PASSIVE AND ACTIVE DUROTAXIS

Patterning droplets with durotaxis

R. W. Style, Y. Che, S. J. Park, B. M. Weon, J. H. Je, C. Hyland, G. K. German, M. P. Power, L. A. Wilen, J. S. Wettlaufer, and E. R. Dufresne, Proc. Nat. Acad. Sci. **110**, 12541-12544 (2013).

Recommended with a commentary by M. Cristina Marchetti, Syracuse University

Durotaxis, a word that combines the Latin adjective *durus* (hard) with the Greek noun $\tau\alpha\xi\iota\varsigma$ (order, position) is the term used in biology to describe the spontaneous motion of adherent cells from soft to stiff regions of the substrate. The remarkable ability of many cell types to sense the mechanical properties of their environment and to respond to it has been demonstrated by a substantial body of experimental observations [1]. This behavior is believed to involve both active sensing and complex biomechanical signaling pathways mediated by spatially localized adhesion sites known as focal adhesions that link the substrate to the contractile acto-myosin network. Focal adhesions are known to consist of a very large number of different proteins, but the mechanisms through which they sense, transmit and respond to mechanical cues are not fully understood.

In this paper Style *et al.* demonstrate that passive liquid droplets are also capable of "sensing" the stiffness of the substrate and to migrate accordingly. Unlike cells that prefer hard substrates, droplets preferentially migrate towards soft regions. Of course droplet "durotaxis" is driven entirely by physical mechanisms and force balance. For a droplet on a hard substrates the equilibrium condition is obtained by balancing all interfacial forces between droplet, vapor and substrate in the direction tangent to the substrate surface. This leads to the well known Young equation for the equilibrium contact angle θ_c (see Fig. 1). Recent work by the the same group [2] has shown, however, that this simple condition fails on soft substrates as the droplet deforms the substrate, raising a lip or ridge around the contact line, as shown in Fig. 2. The deformation of the substrate results in an *apparent* contact angle θ defined in Fig. 2 that is smaller than expected from Young's law. The apparent contact angle is smaller the softer the substrate. On substrates of varying stiffness this yields the anisotropic shape of the droplet contact line shown in Fig. 3. Ironically, in spite of the failure of Young's law, the notion of contact angle remains helpful here as droplet

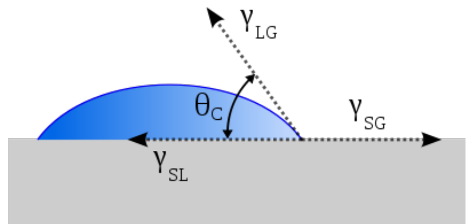

FIGURE 1. A droplet on a hard substrate and the Young contact angle construction.

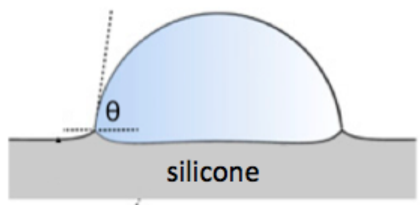

FIGURE 2. A droplet on a soft substrate deforms the substrate, raising a ridge around the contact line.

durotaxis can be understood in terms of the difference in the apparent Young contact angles shown in Fig. 3 that creates an effective wettability gradient and drives droplet motion. It is well known that droplets can be driven by gradients in wettability created, for instance, by externally imposed thermal or chemical gradients, but the mechanism proposed by Style *et al.* is remarkable in its simplicity. Substrate deformations are most significant for small droplets, which behave like droplets on the surface of a liquid [3]. The droplet size below which deviations from Young's law are significant is of order of $10\mu m$ for substrates with Young modulus of the order of kPa. Finally, note that although the simple phenomenological model described by Style *et al.* based on the asymmetry in the classical contact angle describes well the data, there is not a clear first principles rationale as to why this captures the physics.

Style *et al.* exploit this effect to drive and control droplet dynamics. To create substrates of varying stiffness, yet chemically homogeneous and very flat, they deposit a layer of soft silicone gel on a hard graded surface. The softer regions are those where the silicone is thicker. The authors then spray glycerol droplet on the surface with an atomizer and observe them in reflection with a light microscope. The droplets are then found to spontaneously move from hard (thinner) to soft (thicker) regions of the silicone layer. Larger droplets move faster and sometime coalesce once they reach the soft regions.

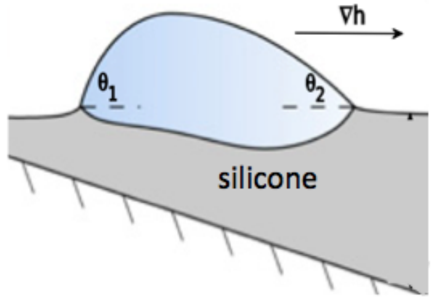

FIGURE 3. A droplet on a substrate with stiffness gradient. The region where silicone is thicker is softer. The apparent contact angle θ_2 in the softer region is smaller than θ_1. The resulting gradient in apparent contact angle drives droplet motion towards the softer region of the substrate.

While a lot of experimental work has gone into measuring the tangential components of the traction forces exerted by cells on substrates, only recently researchers have started to probe the components of such forces that are normal to the substrate and can yield substrate deformations. It is then natural to ask whether cells may be able to appreciably deform soft substrates as droplets do, engulfing themselves in a ridge that may then play a role in driving cell dynamics. It is known that many cells spread out on hard substrates and have more compact morphologies on soft surfaces. It is then tempting to speculate whether substrate deformations and cell engulfment of the type seen for droplets may play a role in controlling this behavior. Of course biochemical signaling is also expected to play a role in controlling the remarkable mechanosensing ability of living cells, but the work by Style *et al.* highlights the need for a careful reanalysis of simple force balance in the study of cell-substrate adhesion.

References

[1] D. E. Discher, P.A. Janmey, and Y. Wang, *Tissue cells feel and respond to the stiffness of their substrate*, Science **310**, 1139-1143 (2005).

[2] R. W. Style, R. Boltyanskiy, Y. Che, J. S. Wettlaufer, L. A. Wilen, and E. R. Dufresne, *Universal Deformation of Soft Substrates Near a Contact Line and the Direct Measurement of Solid Surface Stresses*, Phys. Rev. Lett. **110**, 066103 (2013).

[3] R. W. Style and E. R. Dufresne, *Static wetting on deformable substrates, from liquids to soft solids*, Soft Matter **8**, 7177 (2012).